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Estimating the Offsite Household Damages From Wind Erosion in the Western United States

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Abstract

Wind erosion contributes significantly to particulate air pollution in some regions of the Western United States. As a result, wind erosion imposes damages on households in the form of increased interior and exterior cleaning, reduced recreational opportunities, and impaired health. Costs are difficult to estimate because of limited data availability. However, damages appear to be much larger offsite than onsite.

Keywords: Wind erosion, offsite damages, onsite damages, household damages, Western United States

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Summary

Offsite household damages from all sources of wind erosion in the Western United States may be substantially larger than the onsite damages from wind erosion. Most offsite wind erosion damages occur in the Southwest and the Great Plains, where the highest wind erosion rates occur. The magnitude of offsite wind erosion damages indicates that soil conservation practices aimed at reducing wind erosion on cropland and rangeland could result in significant benefits, probably greater than the onsite benefits. Therefore, targeting soil conservation practices toward reducing offsite particulate damages rather than onsite productivity damages may have a higher payoff.

Offsite wind erosion damages are estimated by extrapolating data from a New Mexico wind erosion study to other regions of the Western United States. The New Mexico data are adjusted to account for potentially overestimated interior and exterior household cleaning costs. Both adjusted and unadjusted data are used to estimate offsite damages. The rate of wind erosion, total tons of wind erosion, population size and density, and the number of wind erosion days are used as variables to estimate costs.

Two methods of extrapolating the New Mexico data are used. One method uses total tons of wind erosion as a proxy for the extent of wind erosion damages, while a second method uses wind erosion days to measure effects. The wind erosion day method using adjusted New Mexico data is judged to be more reliable. Further research is needed to provide improved data and a better understanding of offsite wind erosion effects.

These improvements can more accurately estimate offsite costs. The estimates indicate that substantial offsite damages occur as a result of wind erosion.

Estimating the Offsite Household Damages From Wind Erosion in the Western United States

Steven Piper
Linda K. Lee

Introduction

Many areas of the Western United States are characterized by low average rainfall, frequent droughts, and relatively high wind velocities. These conditions, when combined with erosive soil types and sparse vegetative cover, make some regions susceptible to wind erosion problems. According to the Soil Conservation Service (SCS), about 2 billion tons of soil erode each year from non-Federal land due to wind, nearly 90 percent of it in the region west of the Mississippi River (26).1/ Wind erosion accounts for about 37 percent of the total tons of soil eroded in the United States.

The 1982 National Resources Inventory (NRI) indicates that wind erosion is almost exclusively a western problem, in contrast to water erosion, which occurs in almost every region of the United States (26). About 94 percent of all wind erosion on non-Federal land occurs in the Western United States, with 62 percent of the total in the Great Plains. By comparison, 46 percent of all sheet and rill erosion on non-Federal land occurs in the West.

About 4.8 million cropland acres were damaged each year in the Great Plains as a result of wind erosion since 1955 (2,8). During 1955-57, over 11.5 million acres were damaged each year, while damages were limited to less than 5 million acres per year during 1958-74. Damages in the Great Plains since 1974 have risen, averaging about 6 million acres per year.

Several factors could affect future wind erosion trends. A return to dryland farming could make some areas more susceptible to wind erosion. Declining water tables and increased pumping costs could reduce the profitability of irrigated agriculture in the Great Plains, where the Ogallala Aquifer provides a large portion of irrigation water. Increased competition for water from industries and municipalities in the West may also affect the future of irrigated agriculture. The inclusion of millions of western acres in the conservation reserve created by the 1985 Food Security Act will reduce wind erosion in some regions by removing acreage from crop production.

Wind erosion creates two different types of costs: onsite and offsite. Onsite costs are imposed on farmers and ranchers who own or lease land that is blowing. Onsite costs consist primarily of effects on productivity.

1/ Underscored numbers in parentheses refer to sources listed in the References section.

Offsite costs are imposed on those who live downwind from the source of blowing soil and are adversely affected by particulate pollution associated with wind erosion, which can be severe during duststorms (12). Such costs include increased cleaning and maintenance for businesses and households, damages to machinery, and adverse health effects. The offsite costs of soil erosion have been estimated (3), but the estimated costs did not include the effects from wind erosion.

Our objective was to estimate the offsite household costs from wind erosion in the Western United States. We developed a methodology for determining the offsite costs resulting from blowing soil from the wind erosion and air pollution literature, and we used data from a New Mexico wind erosion study to estimate offsite household wind erosion damages in the West. We included only household damages because previous research indicated that household sector damages account for over 90 percent of total offsite damages (15, 21). We used two methods to extrapolate the data, and we adjusted the New Mexico results to allow for possible overestimation of cleaning due to blowing soil. As a result, we obtained a range of estimated offsite costs.

The Wind Erosion Process

Five factors determine the severity of wind erosion in a particular area. They are soil type, roughness of the soil surface, climate, unobstructed distance across which the wind can blow, and the amount and type of vegetative cover (14, 24). These factors have been incorporated into the wind erosion equation (WEE), which attempts to predict the average annual rate of wind erosion in a given area. The WEE is defined as:

$$E = f\ (I,K,C,L,V,)$$

where:

E = soil loss per acre,
I = soil erodibility index,
K = soil ridge roughness factors,
C = climatic factor,
L = climatic width, and
V = vegetative cover.

Gillette has argued that the WEE was developed from limited data and probably overestimates wind erosion in areas different from Garden City, KS, where it was developed (10). Because better wind erosion data are not available, we used the WEE estimates in this study despite the data limitations.

Very coarse and aggregated soils are less susceptible to wind erosion than fine, disaggregated soils. Ridges or roughness in the soil surface can reduce the potential for blowing soil. Climatic factors (such as windspeed, precipitation, and temperature) influence wind erosion rates. Wind speed and the amount of sediment suspended in the air are positively related, low precipitation reduces cohesion between soil particles and soil aggregation, and high temperatures increase the rate of soil moisture loss and decrease cohesion between particles. The unobstructed length across which the wind can blow affects wind speed and the amount of soil carried offsite. Finally,

vegetation acts as a windbreak and can provide an anchor for blowing soil. Suspension, saltation, and surface creep are the three different modes of transporting soil by wind (14).

Suspension: very small soil particles, less than 100 micrometers (μm) in diameter, are lifted from the land surface and carried several hundred miles downwind. These particles are the most visible effect of wind erosion, but account for only about 10 percent of eroded soil by weight. Most interior cleaning, machinery maintenance, and health costs from blowing soil probably result from suspended soil particles.

Saltation: larger sand particles, 100-500 μm in diameter, are lifted from the surface then dropped because of their weight, causing abrasion of the soil particles. These large particles cannot be transported long distances and typically end up in fencerows, ditches, or along the edges of vegetated areas. Exterior cleaning costs from wind erosion are most likely due to soil transported by saltation. About 50-80 percent of eroded soil is caused by saltation.

Surface creep: particles or aggregates, 500-1,000 μm in diameter, are too large to leave the soil surface in ordinary erosive winds and are pushed and rolled forward by the impact of particles in saltation. Surface creep represents 7-25 percent of all wind-eroded soil by weight.

Types of Offsite Household Wind Erosion Damages

Wind erosion is one of several sources of particulate air pollution in the West. Other sources include industrial processes, automobiles, and natural sources such as pollen. It has been estimated that the median particulate concentration during a duststorm can be as high as 4,850 micrograms per cubic meter (μg/m) (12). By comparison, particulate concentrations in urban areas of the West can be as high as 183 μg/m. Although severe duststorms are fairly uncommon, less severe but more frequent conditions can also increase rural particulate concentrations above urban levels. As a result, wind erosion leads to a noticeable decrease in environmental quality. This reduction in environmental quality can be measured by estimating the damages and costs incurred by households.

Interior and Exterior Damage

Blowing soil can affect interior cleaning by increasing the amount of dust that accumulates around window sills and door thresholds, in carpeting, and on furniture. Additional cleaning time and materials may be needed to clean deposited dust, increasing interior cleaning costs. Blowing soil can increase laundry costs by requiring the use of a dryer during dusty days when clothes cannot be hung outside to dry. Additional costs may also result from the abrasive properties of dust, increasing wear of carpeting and furniture.

Blowing soil can increase the amount of time needed to clean and maintain the exterior of a home, as well as possibly causing landscape damage. Soil can be deposited on sidewalks, patios, driveways, and in swimming pools. In extreme cases, soil can cover grass, fences, and shrubs. Several hours may be needed each week to clean accumulated soil during dusty seasons. Trees, shrubs, and other plants can be damaged if the blowing soil strips leaves or injures bark.

The impact of soil particles against a painted surface can cause chips or scratches, reducing the life of the paint. It may become necessary to paint more often than if blowing soil was not a problem, increasing exterior painting costs. Paint damage can also result in increased weathering or rusting of exposed surfaces.

Blowing soil can increase the costs of automobile maintenance by requiring owners to change filters more frequently and to clean their cars more often. It can also damage automobile paint and glass. Poor visibility caused by suspended dust can contribute to automobile accidents. In severe cases, suspended dust can also shorten a car's engine life.

Health, Recreational, and Other Effects

Blowing soil can impair health in several ways. Suspended dust can aggravate respiratory problems, cause new respiratory problems, and may cause eye problems. Eye problems can be particularly severe for those who wear contact lenses. Short-term effects include difficult breathing, irritated eyes, and an irritated throat. In addition to these short-term effects, longer term respiratory and vision problems can also result. Different medications may be purchased to minimize short-term health problems, increasing medical expenses. As a result of health problems from blowing soil, days may be lost from work.

Blowing soil can have an adverse effect on recreation by reducing the enjoyment of an outdoor activity. A recreational trip that would be made under clear and calm conditions may be canceled when dust is blowing. Picnicking, camping, boating, fishing, swimming, and outdoor games can be adversely affected by duststorms.

Other effects that may result from blowing soil include damages to wildlife habitat, possible water pollution effects from nutrients attached to blowing soil, increased cleaning and maintenance for businesses and government, and a less attractive landscape.

Methodology for Estimating Offsite Wind Erosion Damages

Several methods can be used to measure offsite wind erosion damages. One measure estimates the cost of averting the effects created by blowing soil. Time spent cleaning wind-blown soil inside and outside the home, costs of repairing physical damage, and costs of preventive maintenance and medical expenses can be used to estimate the costs of blowing soil. A second measure of offsite damages is the change in household cleanliness plus the change in cleaning time (household welfare) due to blowing soil. By estimating demand and supply functions for household cleanliness, unobservable changes in cleanliness, which are not reflected through averting expenditures, can be included in the damage estimates. A third measure is contingent valuation, where those affected by blowing soil are asked how much they are willing to pay to control blowing soil.

Each of the three methods has been used in past studies to estimate environmental damages from particulate air pollution. A study of cleaning expenditures in two Ohio Valley cities showed a positive correlation between cleaning costs (averting expenditures) and particulate pollution levels (20). In two separate studies of household cleaning costs from particulate air

pollution in Philadelphia by Watson and Jaksch (30) and by Ridker (23), no correlation was found between particulate pollution levels and cleaning activity.

In the Philadelphia study, the change in the supply of and demand for cleanliness was also estimated (30). A physical soiling function and a behavioral frequency-of-cleaning function were estimated to link air pollution levels with changes in cleaning behavior. The results indicated that although the amount of cleaning was not significantly different for different particulate levels, the level of cleanliness was significantly different. In the study by Ridker, households were found to be willing to pay for an improvement in particulate pollution levels even though the amount of cleaning was not significantly affected by particulate levels (23).

The available air pollution literature indicates that estimating household cleaning damages through avoidance expenditures may substantially underestimate actual damages. Damages also include changes in cleanliness that are not reflected in expenditures. To measure nonexpenditure damages, information is needed to estimate a physical damage function and a behavioral frequency-of-cleaning function. Watson and Jaksch were able to estimate these functions from previous studies and surveys, which included particulate damage data, socioeconomic data, cleaning attitude information, and cleaning frequency data.

The methodology used by Watson and Jaksch cannot be applied to wind erosion damages for two reasons. First, the behavioral information needed for the methodology proposed by them is not available for wind erosion damages. Second, urban particulate pollution and wind erosion are different processes and produce different offsite effects. Urban particulate levels are fairly constant in a particular area, while rural wind erosion particulates are highly variable. As a result, rural wind erosion damages may be more obvious than urban particulate damages because of the relatively sudden and severe effects from blowing soil. Thus, rural wind erosion could have a greater impact on cleaning activity than urban particulate pollution.

For these reasons, this study uses the approach of averting expenditures to estimate offsite household cleaning damages from wind erosion in the Western United States. The only literature that reports offsite damages from wind erosion are two studies on the costs associated with averting wind erosion damages in New Mexico (15, 21). In these studies, the damages imposed on the household, business, and government sectors of the economy were estimated through a survey of averting behavior expenditures. We use data from the New Mexico studies to illustrate the potential offsite wind erosion damages for the Western United States. First, regions sustaining wind erosion damages are identified using data from USDA's Soil Conservation Service. Households within these regions are assumed to experience offsite damages from blowing soil. Second, the number of households per region is estimated using U.S. Census Bureau data. Finally, the New Mexico survey data are used to develop damage estimates per household for each region. These costs are aggregated to estimate total household offsite damages in the Western United States.

Two methods are used to extrapolate the New Mexico data to other regions of the West. The first method, the cost per ton per household density method, assumes that total tons of soil erosion in an area is a good proxy for the magnitude of offsite damages. The second method, the cost per household per wind erosion day method, assumes that the number of days per year that wind

erosion creates noticeable effects is a good indicator of the level of offsite costs. Both methods have shortcomings that likely produce errors in estimating offsite costs.

There are several limitations with the methodology in addition to the potential underestimation of cleaning damages and uncertainty in measuring the amount of wind erosion. Perhaps the most severe limitation is the underestimation of health costs. Health costs from air pollution are large, estimated to be over $2 billion per year in a 1970 study (17). Health costs include medical treatment, reduced physical activity, shortened life expectancy, days lost from work, and pain and suffering. Studies have shown a significant correlation between respiratory disease and air pollution as well as a correlation between particulates and death rates (17). Since the averting expenditures approach does not measure treatment costs, total wind erosion damages may be underestimated.

The New Mexico Study 2/

The methods used to estimate offsite damages in the New Mexico study included mail surveys, telephone interviews, and personal interviews. The household sector costs were estimated through a mail survey sent to 900 randomly selected households with 240 usable questionnaires returned. The business sector costs were estimated using a mail survey and personal interviews.

The mail survey data from households were used to estimate average costs per household expanded to measure total costs imposed on all households. The offsite damages were aggregated into major land resource areas (MLRA's), which are areas with similar geographic and climatic conditions, and then further aggregated into damages for all of New Mexico. Total offsite damages were estimated to be $465.8 million per year for the household, business, and government sectors combined. Household damages averaged $980 per household each year in 1984 dollars. Of the $465.8 million in offsite damages, $457.6 million (98 percent) of the total damages are imposed on the household sector. Since the household sector accounts for almost all offsite costs, the government and business sector costs are not included in the offsite damage estimates for the West.

Potential Estimation Problems in the New Mexico Study

Before the New Mexico data were extrapolated to other regions, we examined the results to determine if any damage estimates appeared to be out of line. The increase in exterior and interior cleaning time due to blowing soil appeared to be high compared with total household cleaning time. Household respondents indicated that an additional 4.4 to 11.1 hours were spent cleaning each day the wind created dust problems. The number of dusty days were obtained from New Mexico SCS estimates (11). The average number of hours spent cleaning inside and outside the home, including yardwork, was 2.75 hours per day (25). If the New Mexico estimates are correct, time spent on dust-related cleaning increases two to five times during dusty days.

To add further perspective to the New Mexico estimates of household cleaning time due to dust, the estimates can be compared with the time spent on all household maintenance activities. About 9.9 hours are spent each day by an

2/ The methodology summarized in this section is described in more detail in (21).

average household for all household work, including dusting and vacuuming (25). If the New Mexico estimates are correct, then total hours spent on all household cleaning increased between 44 and 112 percent, averaging 74 percent, on a dusty day. The time spent on dust-related cleaning exceeds the time spent on all other household chores combined. Compared with the time spent on all housework, the estimated New Mexico cleaning hours on a dusty day seem very high for only one aspect of household cleaning.

Other data from the New Mexico survey suggest some possible inconsistencies in the responses. Several respondents indicated blowing dust was not a problem or just a slight problem but at the same time indicated blowing soil caused substantial costs. This apparently contradictory result was most obvious for the interior and exterior cleaning categories. The high interior and exterior cleaning costs could be due to the difficulty in distinguishing between cleaning because of blowing soil and cleaning that would be necessary under normal circumstances.

Another interpretation could be that although additional time is spent cleaning as a result of blowing soil, cleaning is necessary but not a problem. Cleaning due to blowing soil may impose costs, even though cleaning may not be perceived as a problem.

To account for the possible overestimation of damages, we adjusted the New Mexico data. We assumed household cleaning damages to be zero if a respondent indicated that blowing soil is not a problem or is a slight problem, even if damages were indicated. Some costs are associated with cleaning wind-blown soil even if it is not considered a problem, and by assuming zero costs, damages are underestimated. However, the costs for those not indicating a severe problem may be relatively low and the underestimation of damages using the adjusted data may be small. The adjusted data are used as a lower estimate of damages.

When using the adjusted data, the estimated total offsite household damages in New Mexico are reduced by about a third and the additional cleaning time for each household on a dusty day ranges from 1.1 to 7.2 hours. This range is relatively low compared with a high of 11.1 additional cleaning hours from the unadjusted data. The adjusted labor hours remain fairly high compared with the average 2.75 household-cleaning-hours per day under normal circumstances.

Estimating Offsite Wind Erosion Costs

The New Mexico data indicate that offsite damages resulting from wind erosion in New Mexico can be significant in areas where wind erosion occurs. Offsite damages would also be expected in other areas of the Western United States where wind erosion occurs. The New Mexico study provides a basis for assessing offsite damages in those areas.

Three steps are necessary in estimating the offsite costs of wind erosion in the Western United States. First, we adjusted the New Mexico data to account for a possible overestimation of interior and exterior cleaning costs and to provide a range of damage estimates. We did not adjust noncleaning damages. Second, we used wind erosion rate and population density criteria to categorize each New Mexico MLRA and other western MLRA's so that the New Mexico offsite costs can be extrapolated to other areas with similar physical

characteristics. Third, we applied the unadjusted and adjusted New Mexico offsite damage estimates to other western areas to estimate offsite household costs. We used the total number of households, total tons of wind erosion, number of wind erosion (or dusty) days per year, and size of a region as variables to estimate offsite costs using two different methods.

Criteria for Expanding the New Mexico Offsite Cost Estimates to Other Regions

We used two criteria, the rate of wind erosion and population density, to determine which New Mexico survey region cost estimate to apply to each western MLRA. We also used these criteria to eliminate regions with very low offsite damages. Once we arrived at the appropriate cost estimates, we used one of two methods of extrapolating offsite costs to estimate a range of costs.

Wind Erosion Rate Categories

The rate of wind erosion has a large impact on the offsite damages imposed on the household sector. Higher rates of wind erosion generate higher offsite damages. However, the relationship between wind erosion and damages is not likely to be linear. For example, the adjusted annual offsite household costs in New Mexico survey region MLRA 36 in the northwest corner of the State are $732 per household, $1,128 per household in MLRA 70 in the central part of the State, and $1,047 per household in MLRA 77 in the eastern part of the State. The wind erosion rates in the three areas are 1.2 tons per acre per year (TAY), 1.9 TAY, and 6.7 TAY. Offsite costs increase 54 percent from a low-erosion area to a moderate-erosion area, while offsite costs are virtually identical for the high-erosion and moderate-erosion areas. Higher rates of wind erosion do not necessarily result in proportionately higher offsite household costs.

The high offsite costs in a moderate-erosion area compared with a low-erosion area and the similar costs for moderate-erosion and high-erosion areas can be partially explained by the concept of wind erosion damage thresholds. A wind erosion threshold represents a wind erosion rate where cleaning becomes necessary if wind erosion is above the threshold or cleaning is no longer necessary if wind erosion is below the threshold. If a threshold is passed in an area, then different cleaning methods or time may be needed to take care of blowing dust compared with a lower erosion area. As a result, damages in a higher erosion area (MLRA 70) are larger than in a lower erosion area (MLRA 36). If a threshold is not passed, then damages can be similar between areas despite differences in erosion rates, such as MLRA 70 compared with MLRA 77. Separating the New Mexico MLRA survey areas into wind erosion rate categories, then applying the New Mexico costs to other regions of the West according to these categories, can account for some of these hypothesized thresholds.

The average rate of wind erosion in New Mexico ranges from 0.2 TAY in MLRA 48/51 to 6.4 TAY in MLRA 77. An erosion rate of 5 TAY or more is the high-erosion category because 5 TAY is considered the maximum allowable soil loss tolerance for cropland. The division between moderate-erosion and low-erosion categories is not as clear as for the high-erosion category. A wind erosion rate of 1.9 TAY is the boundary chosen between the low-erosion and moderate-erosion categories based on the distribution of wind erosion rates in New Mexico. Wind erosion thresholds may also exist within each of the erosion rate categories, and costs may not be estimated correctly within

these categories. Nonetheless, these three wind erosion categories should result in more accurate offsite cost estimates.

Urban-Rural Population Density Categories

Population and the wind erosion rate are major factors in determining the level of total offsite costs imposed by wind erosion; other factors also play important rolls. MLRA's 36 and 70 have very high offsite costs per household despite low rates of erosion. Both of these regions have a higher cost per household than MLRA 42, which is a high-erosion area. Wind erosion thresholds may account for some of the variation in offsite costs, but thresholds cannot explain why some low-erosion regions have higher offsite costs per household than some higher erosion areas. One factor that may contribute to these apparently inconsistent results is that buildings in urban areas may act as windbreaks.

Physical geology and sand dune literature indicate that physical barriers, (like buildings) create wind shadows where soil can accumulate (1, 18). If soil is deposited near buildings on the periphery of an urban area, less soil is available to create further damages downwind, so average costs per household in downwind areas may be lower. Less densely populated areas have fewer buildings to act as windbreaks. As a result, the average offsite cost per household is higher in rural areas than urban areas with similar erosion rates.

The urban distinction would apply only to the larger sand particles, which cannot be lifted to high elevations and which can be blocked by buildings (9). Small particles can be lifted hundreds of feet into the air and carried up to 500 miles before being deposited (6). This material is deposited vertically and urban buildings would likely have little or no effect on household cleaning and maintenance caused by such dust (19). As a result, the offsite costs per household within an urban area are likely to be less than the costs in rural areas due to protection from larger particles, but offsite effects are still likely to occur in higher erosion urban areas due to vertical movement of small particles.

The New Mexico data support the urban-rural cost distinction. The average population density in New Mexico, 12 persons per square mile, is used as an urban-rural division for classifying population density. When the New Mexico survey regions are separated into urban and rural population regions, offsite costs per household generally vary according to the rate of wind erosion. The only areas that do not vary according to the rate of wind erosion are MLRA's 70 and 77, which have similar costs per household. Data in table 1 compare offsite costs with the rate of wind erosion and the population density in each New Mexico area.

The estimated costs per household in each case are higher in rural areas than in urban areas with a similar rate of erosion. The differences are so great that the costs per household in the low-erosion rural area of MLRA 36 are greater than the costs in the high-erosion urban area of MLRA 42. Because the urban-rural distinction appears to explain some of the variation in offsite costs, it is one of the criteria used with wind erosion rate for extrapolating the New Mexico data. Table 2 outlines the wind erosion rate and population density categories and indicates the New Mexico MLRA's that fit into each category.

Table 1--Adjusted offsite household costs: Rate of wind erosion and population density in each New Mexico major land resource area

MLRA	Population density per square mile	Wind erosion rate	Adjusted offsite household costs per household
Urban:	Persons	TAY	Dollars (1984)
42	17	6.1	580
37	17	2.8	496
48/51	12	.2	102
Rural:			
77	8	6.7	1,047
70	3	1.9	1,128
36	8	1.2	732

Table 2--New Mexico major land resource areas by rate of wind erosion and population density

Wind erosion rate	Rural ($\leq$ 12 persons/mi^2)	Urban (> 12 persons/mi^2)
High erosion: ($\geq$ 5 TAY)	MLRA 77	MLRA 42
Moderate erosion: (1.9-4.9 TAY)	MLRA 70	MLRA 37
Low erosion: (<1.9 TAY)	MLRA 36	MLRA 48/51

Exclusion of Some Regions

There are 105 MLRA's in the Western United States. Not all have offsite wind erosion problems. Table 3 indicates the distribution of MLRA's by wind erosion rate and population density. Areas with extremely low rates of wind erosion are likely to have little or no offsite costs. The wind erosion rate and population density criteria exclude areas with a high likelihood of zero or near zero offsite costs.

Twenty MLRA's in the West have a zero rate of wind erosion (26), and offsite costs in these areas are assumed to be zero. Sixty additional western MLRA's have wind erosion rates less than 1.9 TAY, but greater than zero (26). All of these areas, however, cannot be excluded because the New Mexico results indicate that offsite costs can be large in some low-erosion areas. The New Mexico data also show that large offsite costs occur when the population is large enough to create such costs, but small enough that windbreaking effects from buildings are minor.

Table 3--Western U.S. major land resource areas by rate of wind erosion and population density

Wind erosion rate	Rural ($\leq$ 12 persons/mi^2)	Urban (> 12 persons/mi^2)
	Number of MLRA's	
High erosion:		
($\geq$ 5 TAY)	5	4
Moderate erosion:		
(1.9-4.9 TAY)	11	5
Low erosion:		
(< 1.9 TAY)	68	12

Areas that have a low rate of erosion, less than 1.9 TAY, and a population density of less than 2 persons per square mile or a density greater than 12 persons per square mile are excluded from these cost estimates and assumed to have zero offsite costs. MLRA 48/51 in New Mexico fits into this category and accounted for only 2 percent of the total New Mexico offsite costs (21). The 36 western MLRA's excluded from the western offsite cost estimates using these criteria account for about 2 percent of the total tons of wind erosion in the West. Therefore, excluding these MLRA's is likely to have a minor effect on the offsite household cost estimates.

Extrapolating the New Mexico Offsite Cost Estimates to Other Regions

We used two methods for extrapolating the New Mexico data to other areas. One method uses total tons of wind erosion as a proxy for wind erosion damages, while a second method uses wind erosion days to measure the effects.

Cost Per Ton Per Household Density Method

Using the cost per ton per household density method, the offsite costs in each New Mexico survey area are calculated as follows:

$$CTHD = \frac{THC/WE}{H/A}$$

where:

CTHD = cost per ton of wind erosion imposed on the number of households in a square mile area,

THC = total offsite household costs in an area due to blowing soil,

WE = total tons of wind-eroded soil in an area,

H = total number of households in an area, and

A = total area in square miles.

These costs are then applied to other similar western areas by rearranging terms into the equation:

$$THC = \frac{WE \times H \times CTHD}{A}.$$

Table 4 lists the estimated cost per ton per household density for each New Mexico survey area that is applied to other western areas. The unadjusted data are included in table 4 because they represent the results of the New Mexico survey and can be compared with the adjusted costs. The 1982 National Resources Inventory (NRI) is the source for total tons of wind-eroded soil (26). Wind erosion on Federal land is not estimated in the NRI; therefore, tons of erosion on Federal land are estimated using an average rate of wind erosion on range and forest land and total Federal acres within an MLRA. The number of households in each region was estimated using Bureau of the Census data (29). A Soil Conservation Service handbook is the source of data for MLRA acreage (28).

There are several limitations with this method of extrapolating offsite costs:

1. Total tons of wind erosion in an area may not be proportionately related to offsite damages in that area.

2. Wind erosion based on the wind erosion equation may have a large degree of error.

3. Offsite costs within wind erosion categories are assumed to increase linearly with increased erosion, although damage thresholds may exist.

4. Population and tons of wind erosion are assumed to be spread evenly over an area, ignoring the location of wind erosion sources relative to population areas.

5. The relationship between the rate of wind erosion and damages from the New Mexico study are assumed to apply throughout the West.

Cost Per Household Per Wind Erosion Day Method

Using the cost per household per wind erosion day method, the offsite costs in each New Mexico survey area are calculated as:

$$CHWD = \frac{THC/H}{WD}$$

where:

CHWD = total cost imposed on each household on a wind erosion day,

THC = total offsite household costs in an area due to blowing soil,

H = total number of households in an area, and

WD = total number of wind erosion or dusty days in an area.

Table 4--New Mexico costs per ton of wind erosion per household

MLRA	Unadjusted	Adjusted
	1984 dollars	
36	1.13	.74
37	.56	.30
42	.71	.39
48/51	10.17	1.96
70	.94	.81
77	.50	.35

The cost per household in each MLRA is estimated using Bureau of the Census data (29). The number of wind erosion days in each area is estimated from information provided by SCS personnel in 19 Western States (27). Table 5 shows the estimated offsite cost due to blowing soil each dusty day for each New Mexico survey area.

SCS State and county personnel provided estimates of the number of weeks per year that wind erosion imposed offsite costs on households in different counties of the Western United States. We then estimated the average number of weeks for each MLRA from counties within each MLRA. The results demonstrated that there was a large variation in wind erosion day estimates between MLRA's with similar erosion rates in the same general area and between counties with common borders. In some cases, only two or three county estimates of wind erosion days were available to derive MLRA wind erosion day estimates. As a result, the MLRA estimates are aggregated to larger land resource regions (LRR's) to reduce some of the variation in the MLRA estimates (fig. 1). The estimated number of wind erosion days by LRR are presented in table 6.

This method of estimating offsite costs has several advantages. The number of days blowing soil creates offsite effects is a more direct measure than the total tons of eroded soil. Another advantage of this method is that some cultural and socioeconomic variables may be taken into account. Estimates by SCS personnel of the days that wind erosion creates offsite effects may be affected by differences in style and size of homes or household activities in different regions. A third advantage is that some thresholds may be accounted for within wind erosion categories. Estimates of wind erosion days within each category varied greatly and did not always vary according to the total tons of wind erosion.

The major problem with the cost per household per wind erosion day method is the uncertainty in estimating the number of wind erosion days in each region. There is no clear definition of a wind erosion day or dusty day, and perceptions of impacts will vary from region to region. The result is a large variation in wind erosion day estimates by different people for the same general areas.

Table 5--New Mexico: Offsite household costs per wind erosion day

MLRA	Unadjusted	Adjusted
	1984 dollars	
36	45	29
37	41	22
42	20	11
48/51	22	4
70	44	38
77	26	18

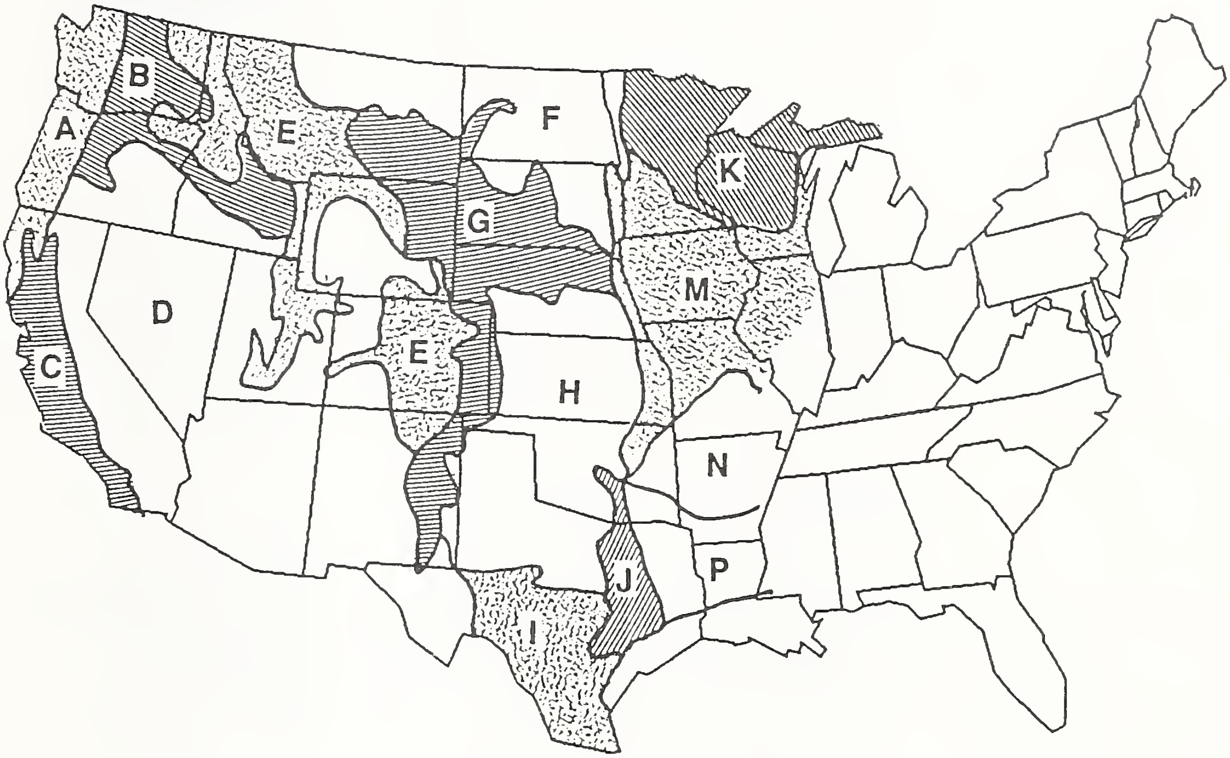
Table 6--Average number of wind erosion days per year in western land resource regions

Land resource region	Wind erosion days per year
	Days
LRR A - Northwestern Forest, Forage, and Specialty Crop Region	0
LRR B - Northwestern Wheat and Range Region	59
LRR C - California Subtropical Fruit, Truck, and Specialty Crop Region	56
LRR D - Western Range and Irrigated Region	48
LRR E - Rocky Mountain Range and Forest Region	28
LRR F - Northern Great Plains Spring Wheat Region	27
LRR G - Western Great Plains Range and Irrigated Region	37
LRR H - Central Great Plains Winter Wheat and Range Region	65
LRR I - Southwest Plateaus and Plains Range and Cotton Region	7
LRR J - Southwestern Prairies Cotton and Forage Region	4
LRR K - Northern Lake States Forest and Forage Region	42
LRR M - Central Feed Grains and Livestock Region	16
LRR N - East and Central Farming and Forest Region	0
LRR P - South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region	0

Estimates of the Offsite Household Damages

The estimated offsite household costs because of wind erosion in the West range from about $4 billion per year using the adjusted cost per household per wind erosion day method to $12 billion per year using the unadjusted cost

Figure 1--Western land resource regions



LRR A - Northwestern Forest, Forage, and Specialty Crop Region
LRR B - Northwestern Wheat and Range Region
LRR C - California Subtropical Fruit, Truck, and Specialty Crop Region
LRR D - Western Range and Irrigated Region
LRR E - Rocky Mountain Range and Forest Region

LRR F - Northern Great Plains Spring Wheat Region
LRR G - Western Great Plains Range and Irrigated Region
LRR H - Central Great Plains Winter Wheat and Range Region
LRR I - Southwest Plateaus and Plains Range and Cotton Region
LRR J - Southwestern Prairies Cotton and Forage Region

LRR K - Northern Lake States Forest and Forage Region
LRR M - Central Feed Grains and Livestock Region
LRR N - East and Central Farming and Forest Region
LRR P - South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region

per ton per household density method (fig. 2). Both methods were estimated using unadjusted and adjusted New Mexico survey data.

The cost per household per wind erosion day method of estimating costs is theoretically the best method for extrapolating the New Mexico data, because offsite damages are associated with noticeable offsite wind erosion effects rather than with a proxy for offsite effects. There is a large amount of variability in the offsite cost estimates using this method because of the difficulty in estimating the number of dusty days in a region. Because New Mexico survey respondents tend to include other sources of damages with the wind erosion estimates, the adjusted costs are likely to be better damage estimates. Therefore, the offsite household damages are likely to be closer to the $4 billion estimate using the dusty day technique and adjusted data.

Figure 2 indicates that the largest damages occur in LRR D (Western Range and Irrigated Region) and H (Central Great Plains Winter Wheat and Range Region). Approximately three-quarters of the total estimated offsite damages occur in these two regions. These results are not surprising considering the climate and land uses in these regions. A large section of LRR D land is desert and rangeland with some irrigated crops, while a large portion of LRR H land is dryland agriculture. These conditions are conducive to wind erosion problems.

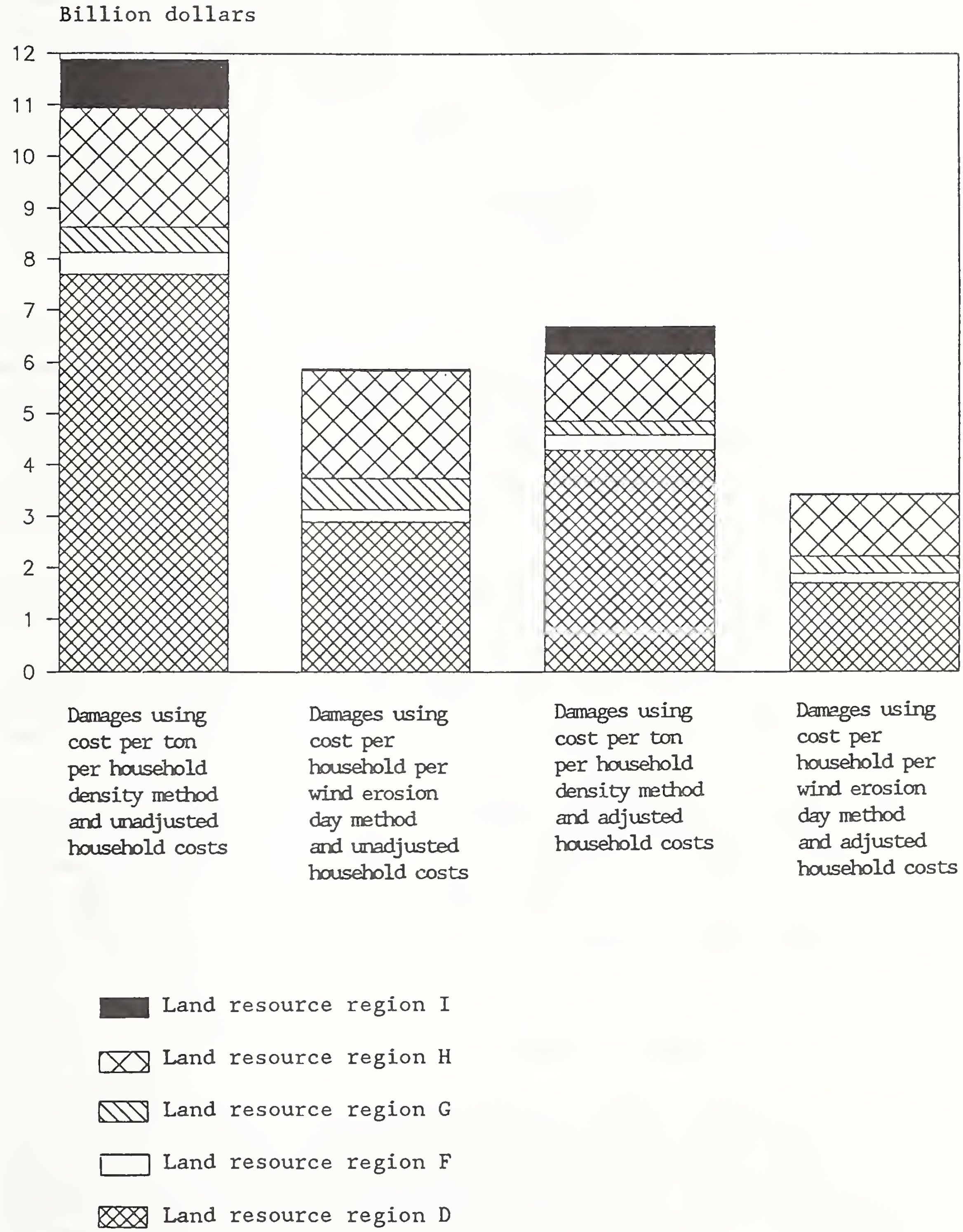
Comparison of Offsite and Onsite Costs

In a study conducted by Davis and Condra, the onsite costs of wind erosion in New Mexico were estimated to be about $10 million annually (5). The study described four different types of onsite costs: 1) those incurred by producers to control wind erosion damages through conservation practices, 2) those associated with damage to crops from blowing soil, 3) those due to decreased productivity of the land, and 4) indirect onsite costs, such as damage to machinery or increased machinery repairs.

The costs of controlling wind erosion were estimated through sample surveys and personal interviews with producers, USDA field personnel, and New Mexico State University scientists. A total of 252 farmers were selected at random from MLRA's 77, 70, and 42 and sent a questionnaire to indicate practices applied to prevent wind erosion. The sample population was limited to these MLRA's because 86 percent of the total cropland in New Mexico is located there. Sixty-two farmers responded to the initial survey, and an additional 26 were contacted by phone. Out of 88 responses, 24 indicated they used wind erosion control practices. Using the survey data, along with information from agronomists in the area, the total acres subject to erosion and the practices used to prevent erosion were determined. The total annual cost of using these control practices was estimated to be $8.4 million.

The costs associated with crop damage from blowing soil were estimated from indemnity payments to producers and survey data. Although the surveys did not include farmers who had received damage payments, data from the Federal Crop Insurance Corporation showed that indemnities paid for wind erosion damage averaged $0.67 per acre insured for wheat, $3.53 for grain sorghum, and $0.21 for cotton. Assuming that the insured acreage represents only 10 percent of the total crop damage on all acreage and that the average case of wind erosion damage is 40 percent of the worst case of damage, annual damages were estimated at $1.25 million per year.

Figure 2--Offsite wind erosion damages by land resource region



Productivity losses were estimated using the erosion-productivity impact calculator (EPIC) model, which calculates productivity losses for different soil groups and crops. Erosion-productivity coefficients (EPC's), representing the percentage reduction in yield for a given crop associated with the loss of 1 ton of topsoil from wind erosion, were developed using the EPIC model. EPC's could not be generated for irrigated cropland. Therefore, EPC values for irrigated crops were assumed to be the same as for dryland crops on the same soil class. The annual yield decline for each crop was estimated by multiplying the 1982 NRI estimates of total tons of wind erosion by the EPC's. The results showed that the annual yield reductions were very small, from zero for irrigated hay in MLRA 77 to a 0.2-percent decrease for irrigated corn in MLRA 70. Discounting the loss in production over 50 years at 6 percent, the total annual productivity losses are $367,200. The productivity losses account for only 4 percent of the total onsite costs of wind erosion.

A comparison of the estimated offsite and onsite costs of wind erosion in New Mexico indicates that the offsite costs are much larger. Onsite costs amount to only 3.5 percent of the offsite household sector costs, and productivity losses are about 0.1 percent of the cost of offsite household effects. Although estimates of both onsite and offsite wind erosion damages in New Mexico are imprecise because of limited data, offsite costs exceed onsite damage by such a large margin that it is doubtful that improved data would significantly alter this relationship.

EPIC estimates of cropland productivity losses in the Western United States range from zero in the west coast regions to almost a 5-percent loss in the plains of South Dakota over a 100-year period (22). The Great Plains, Southern High Plains, and part of the southern desert in Nevada have the largest productivity losses. Preliminary estimates of the loss in gross product due to wind erosion are about $188 million annually, discounted at a 4-percent rate (22). Over 99 percent of these losses occur in the West and about 65 percent of the losses occur in Texas, Colorado, and Montana.

These data suggest that the onsite productivity losses in the Western United States are small compared with the estimated offsite costs, perhaps about 5 percent of the estimated total wind erosion damages. These results, combined with the New Mexico onsite and offsite cost studies, indicate that the magnitude of onsite costs is much smaller than offsite costs. Therefore, the costs of reducing offsite damages may be an important factor to consider when implementing soil conservation practices to prevent wind erosion.

Potential Estimating Problems and Future Research Issues

The estimates of offsite household damages due to wind erosion presented in this report could be improved. Because of the difficulty in defining a dusty day and the lack of available data, the total household offsite costs could be overestimated in some regions and underestimated in others. The Big Spring, TX, area within LRR H, averaged 27 dusty days per year from 1953-70 (7). The number of dusty days estimated by SCS personnel for all of LRR H was 65 days per year. The difference in the estimates could be due to different definitions of a dusty day, local conditions, or perceptions of the observer.

The offsite damage estimates presented in this report exclude some potentially significant effects at the household level. Long-term health effects from suspended dust particles could occur; however, only short-term treatment costs are included in this study. Of the 240 New Mexico household questionnaires returned, only 1 respondent indicated that blowing soil had contributed to an automobile accident. The cost resulting from the accident was not included in estimating average costs per household because the response was a statistically insignificant number.

Offsite costs of wind erosion that cannot be directly accounted for in the household sector were also excluded from this analysis. The business and government sector costs could be more significant in heavily populated and industrialized regions of the West than in the New Mexico study.

The possible environmental effects of blowing soil are not directly addressed in this report. Surface water quality could be affected by atmospheric deposits of phosphorus attached to very fine soil particles that are dislodged and carried by the wind. Phosphorus contamination as far away as the Great Lakes may be partially attributed to atmospheric deposits from precipitation and dry fallout (16). Other possible environmental effects include the loss of wildlife habitat from wind-blown fields. These effects are not well documented and could not be quantified for this analysis. Nevertheless, the impacts of wind erosion may extend beyond the West and the household sector.

This analysis has implicitly assumed that the source of blowing soil is within the region where damages are estimated. Most of the regions used in this analysis are very large, and this assumption may be reasonable under many conditions. The Great Lakes evidence suggests, however, that the sources of blowing soil creating offsite household damages may not always be readily identifiable. Further research is needed to identify the source of offsite damages from wind erosion.

More research is needed to better estimate the longer term cost to households and the environment that may not be adequately reflected through survey techniques. Research is also needed to refine some of the assumptions made to estimate offsite household damages. Offsite damage data are needed from other regions of the West, because conditions in New Mexico do not necessarily exist in all areas of the West. Different growing seasons and crops, socioeconomic characteristics, and different cultures will likely affect the extent of offsite damages. A more accurate measure of wind erosion days per year is also needed to reduce the variability of the estimates. Additional information is also needed to determine where offsite damage thresholds occur and to better document the urban-rural distinction in offsite damages.

More research is needed to determine the offsite benefits possible from the implementation of soil conservation practices. Treating cropland and rangeland could result in substantially lower benefits than the damages estimated in this study because not all wind erosion can be controlled. The benefits from implementing soil conservation practices need to be compared with the soil erosion costs to target areas where reducing wind erosion is economically efficient. Although extrapolating the New Mexico data to other regions of the West results in imprecise estimates of offsite wind erosion damages, these estimates serve as a beginning from which improved estimates can be made.

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